Multipath Mitigation Algorithm Results using TOA Beacons for Integrated Indoor Navigation

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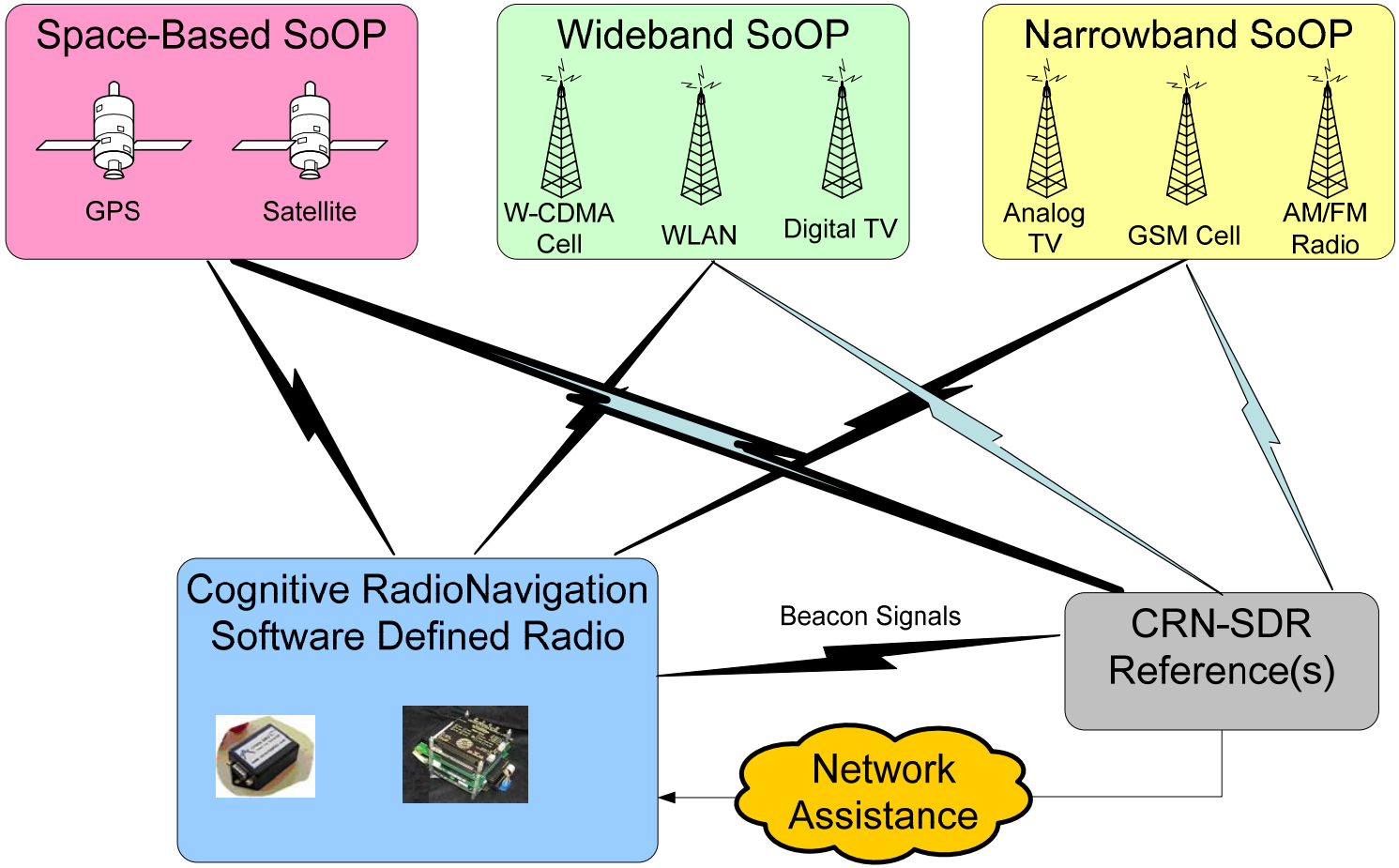
Cognitive RadioNavigation Concept

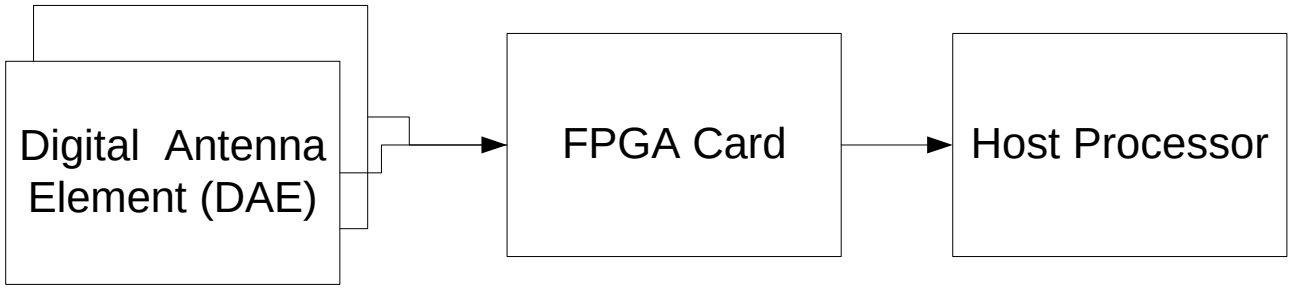


CRN-SDRs use GPS waveform to provide precise “virtual clock” to all Reference units, which enables combination of SoOP and Beacon signals for Nav

Use of SDR Beacons in RSN

- SDR Beacons broadcast TOA signal for RF ranging
  - Enables navigation in the absence of GPS and other signals-of-opportunity
- SDR Reference Units provide common time-base
  - Uses GPS waveform to create a precise “virtual clock” to reference SoOP observations
  - Allows multiple signal sources to be combined in a common navigation solution
- SDR Mobile Units demonstrate inertial-aided multipath mitigation
  - 900 MHz TOA waveform with 10.23 Mbps modulation
  - Enhanced MLE algorithm with inertial/clock-aiding for direct/multipath signal resolution
  - Enhanced fault detection and exclusion (FDE) for GPS and beacon measurements

Benefits of a Software Defined Radio (SDR)

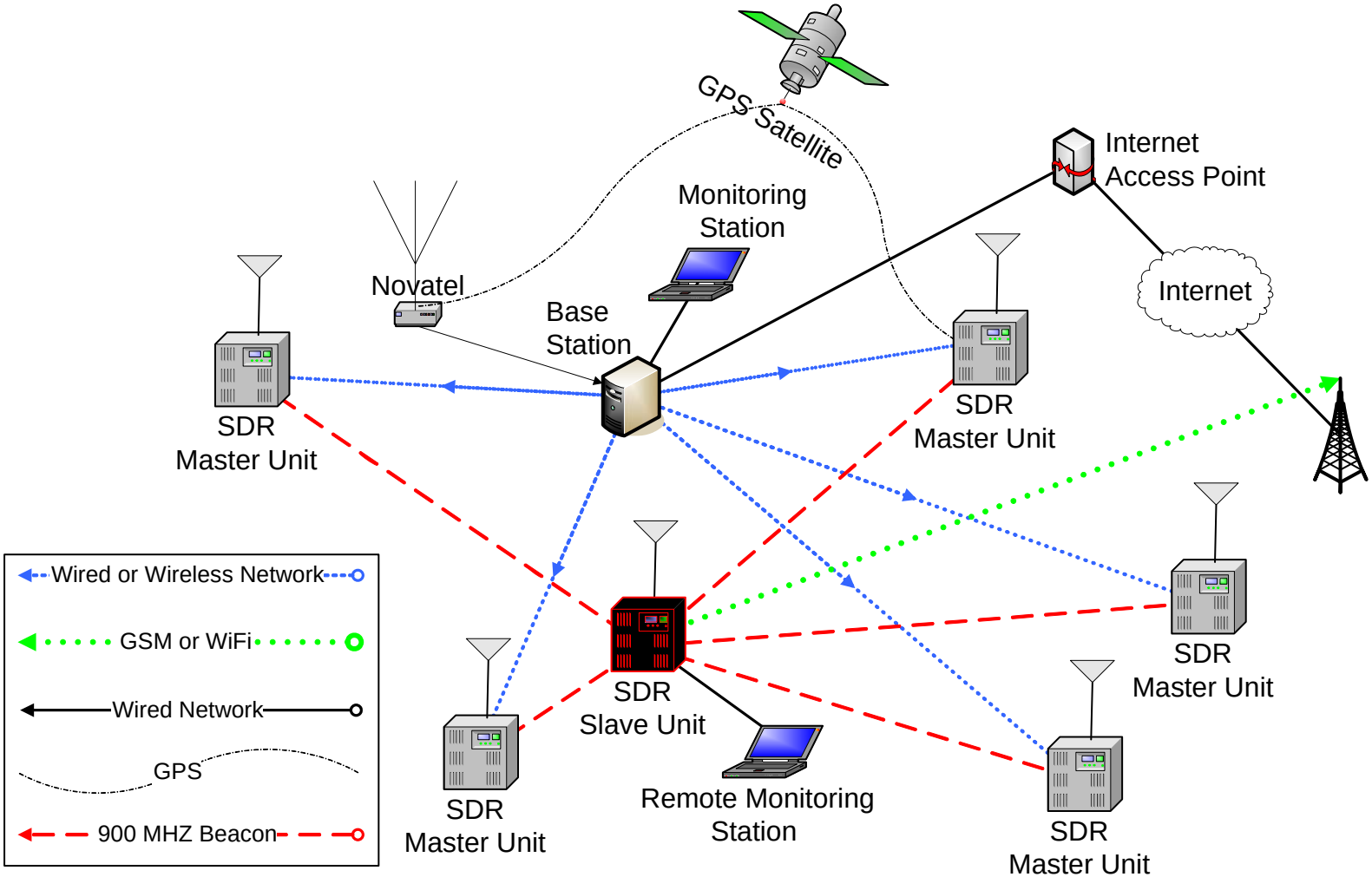


Multiple Frequencies supported by flexible RF/Digital Transceivers

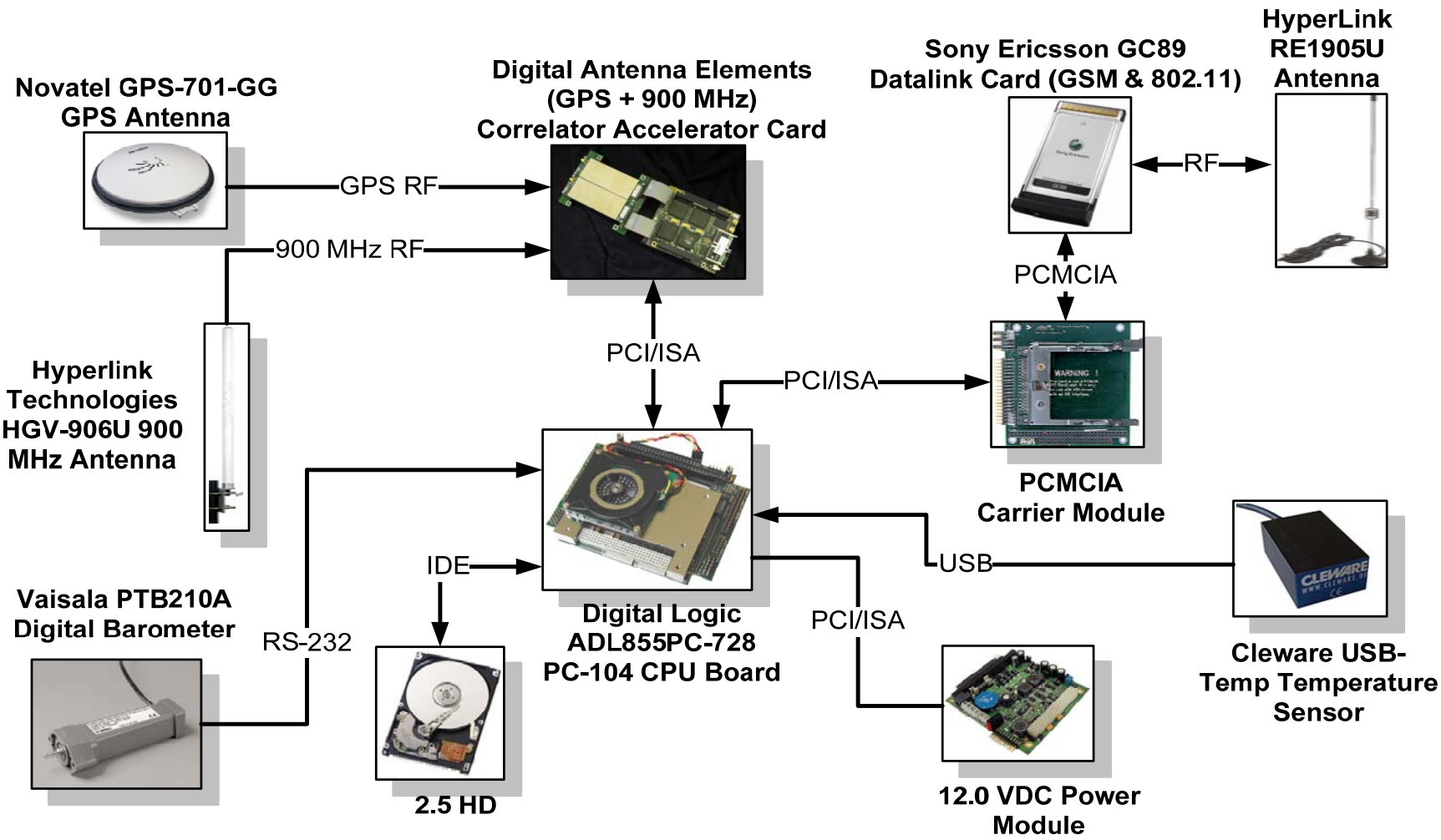
Flexible waveform processing using FPGAs

Software control of SDR configuration and operation

Beacon System Architecture



SDR Master Unit Hardware Design



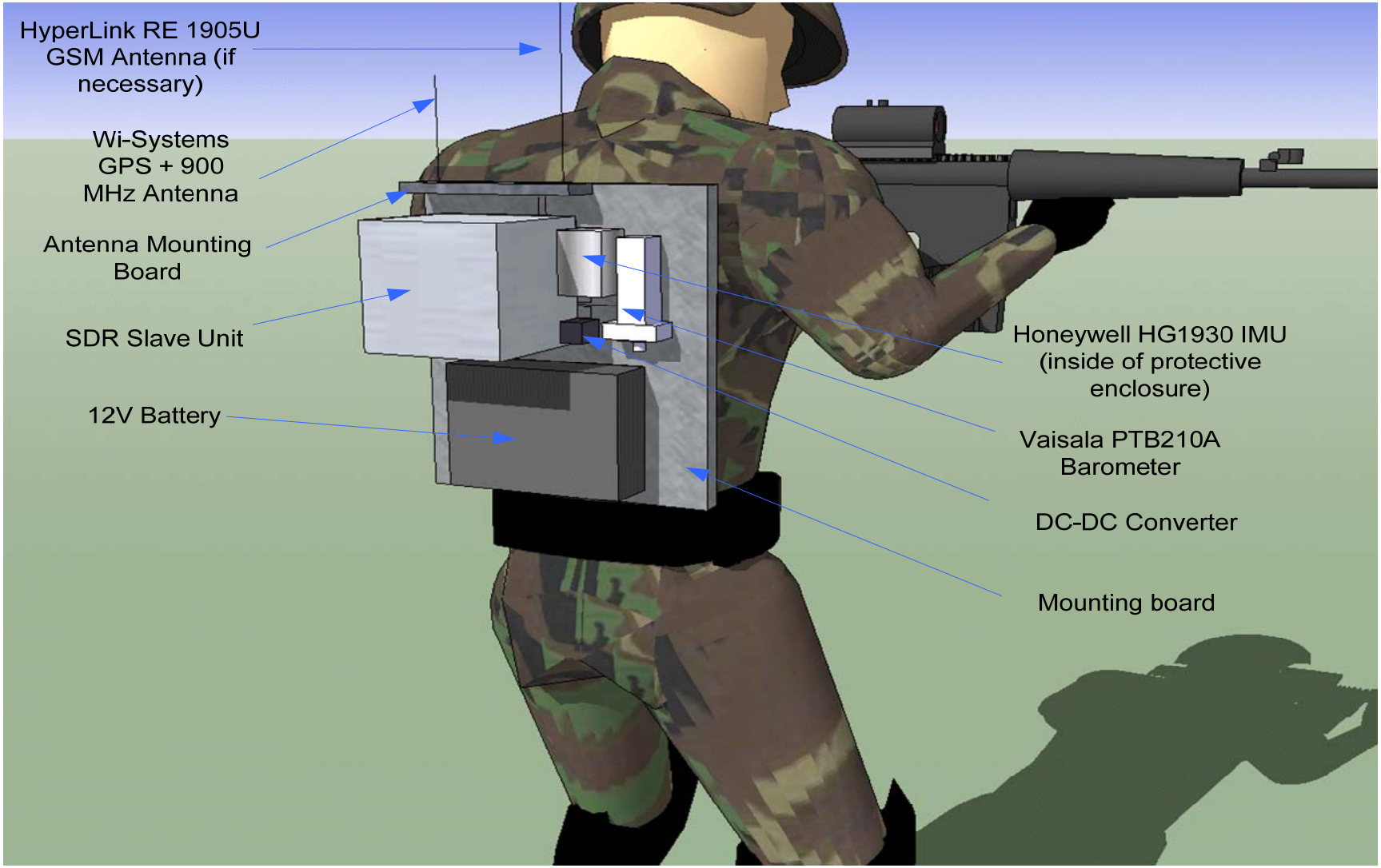
900 MHz TOA Broadcast

- Waveform selection
  - CDMA (PRN code modulated)
  - FDMA (Frequency selectable in firmware)
  - TDMA (Slot selected in firmware)

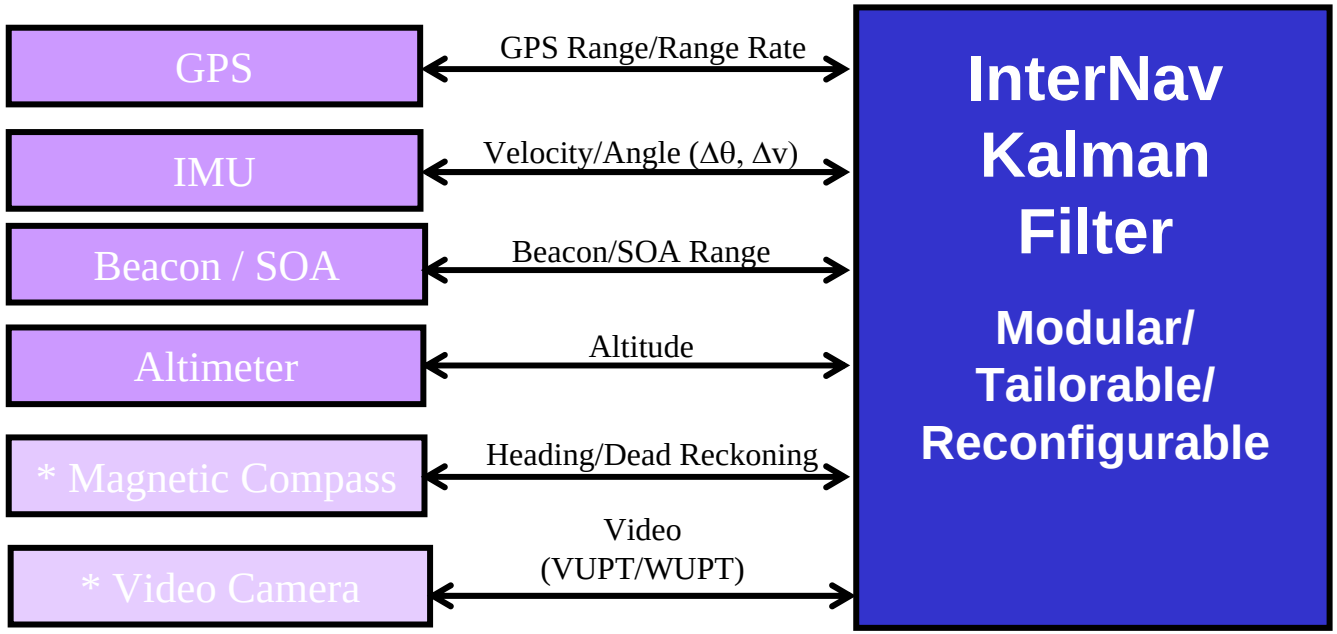
TOA Acknowledge Message broadcast by Pseudolites

Field Name	Units	Description
Time	Week, secs	GPS time of week in msecs of first TOA being transmitted
PRN		ID of PRN code broadcast by pseudolite.
Signal Period	ms	Interval between TOA ranging signals on RF link (0 means transmission will stop)
Signal Duration	ms	Duration of TOA ranging signal on 900MHz link
Signal Freq	MHz	Nominal RF Frequency of TOA ranging signal

SDR Slave Unit Hardware Design



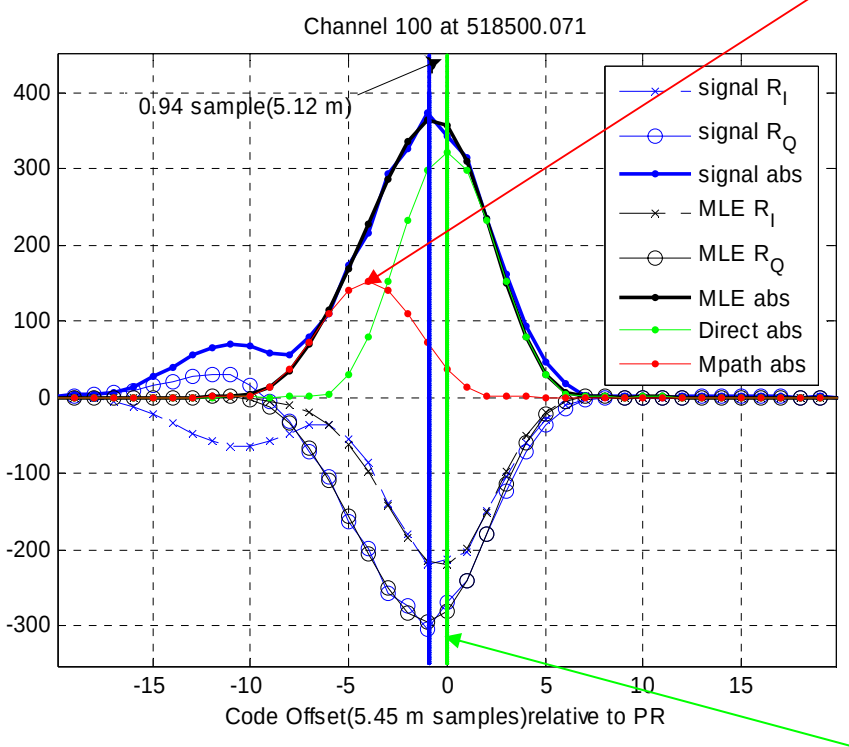
Integrated SDR Navigation Filter

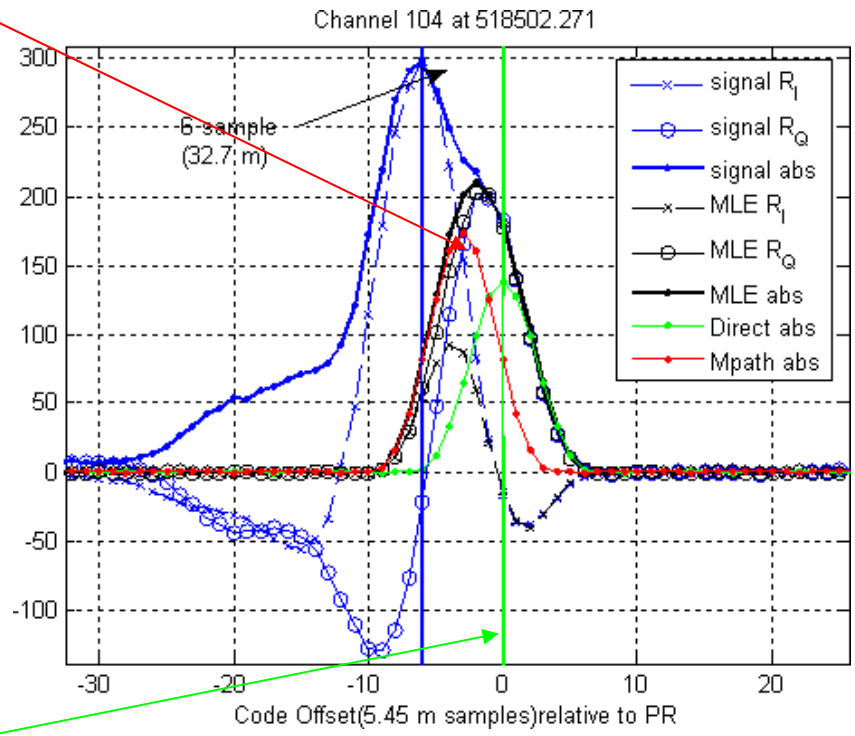


- Under RSN effort, additional functionality was added to the SDR processing to handle beacon and GPS multipath effects
  - MLE-UTC filtering uses inertially aided tracking loops to enable tracking under low power and high multipath conditions
  - GTI-RAIM uses redundent GPS/beacon measurements to perform FDE

MLE-UTC Filtering Algorithm

Multipath Rake Tracking





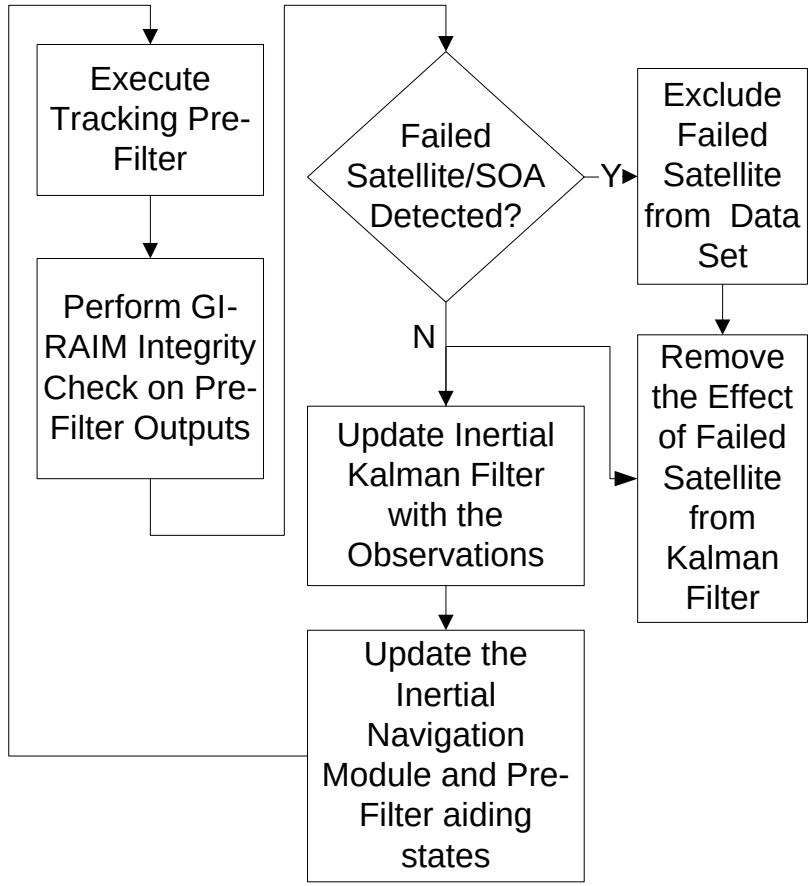
Close-In Multipath

UTC Direct Path Aiding

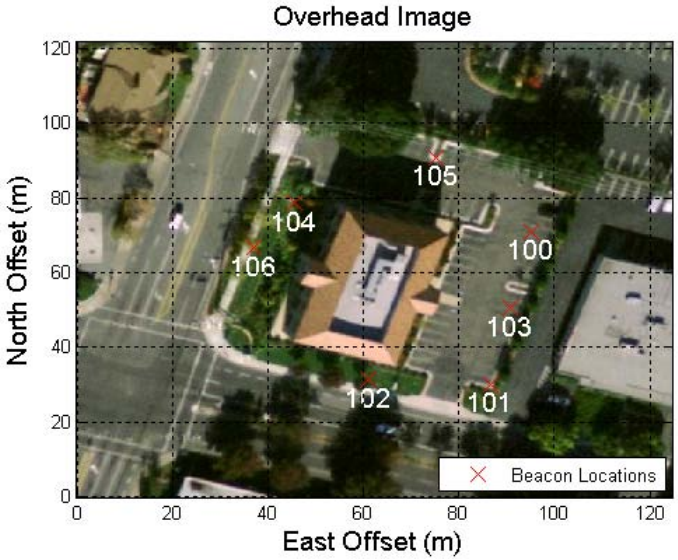
Far-Away Multipath

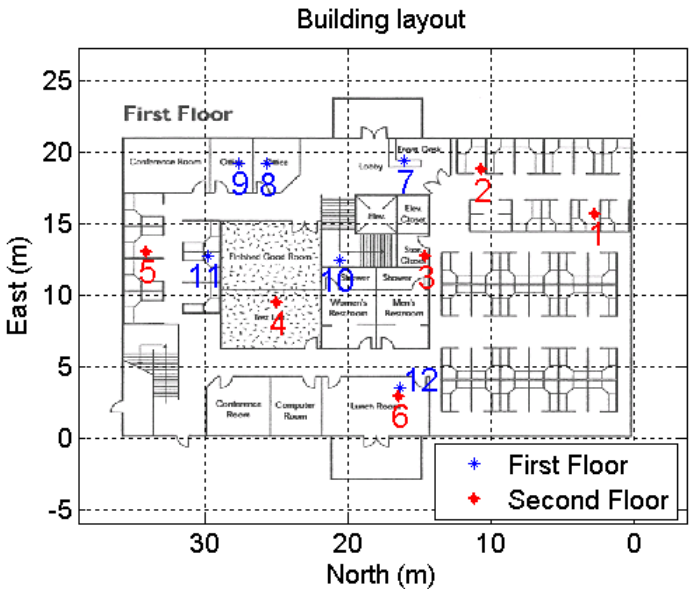
GTI-RAIM Algorithm

- GI-RAIM was previously used to detect and remove out-of-tolerance GPS faults before they are applied to the blended KF solution
- For RSN, FDE solution was extended to detect and reject TOA errors (GTI-RAIM)
- Approach can also be extended to other SoOP using blended RSN solution



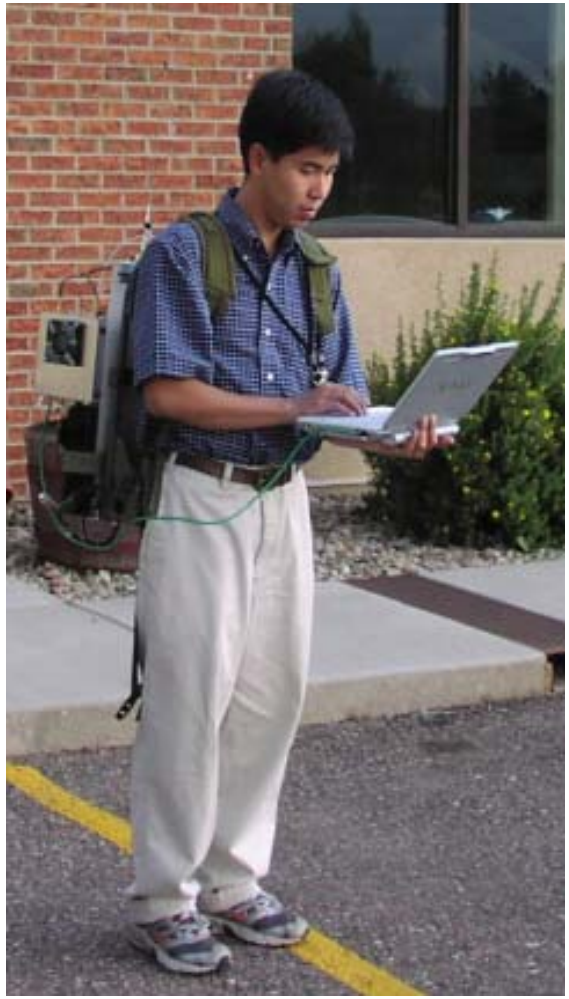
Testing Overview





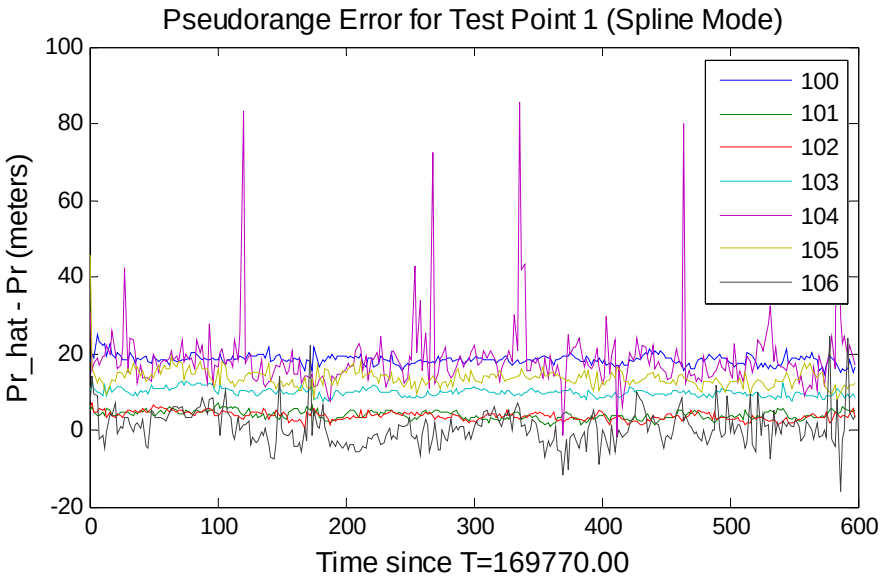
- 7 beacons operating in TDMA mode
  - 2 second frame length
  - 200ms slot length
  - Broadcasting at ~23 dBm
- 1 backpack-mounted receiver with GPS, TOA, IMU and baro
- 12 indoor survey points

SDR Units in the Field

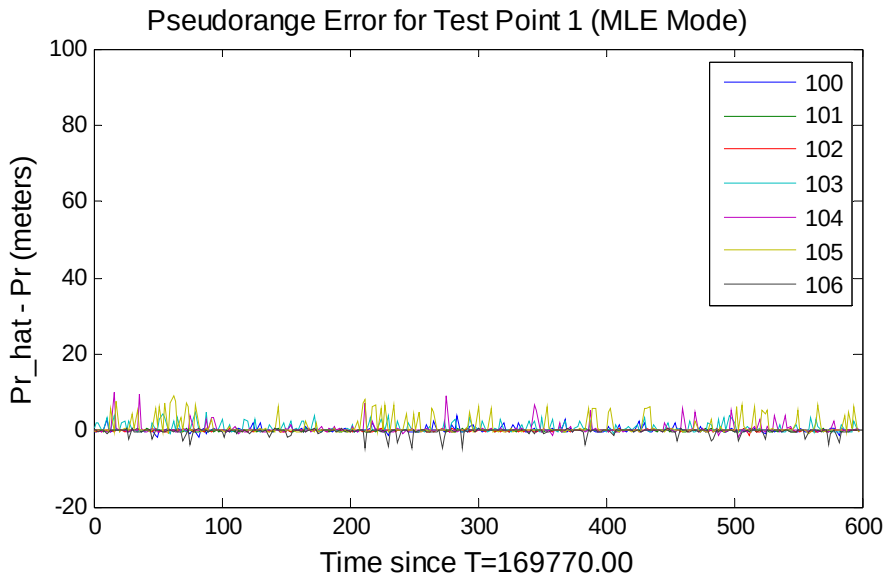


UTC MLE-Aided Filtering Results
Ranging Error
Test Point 1

Spline-Based Peak Detection



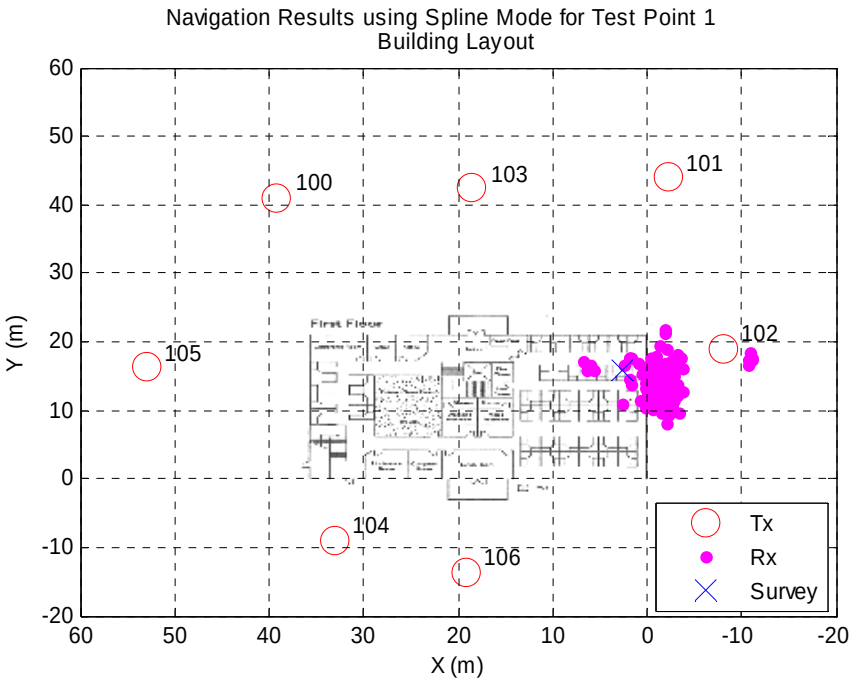
UTC MLE Peak Detection



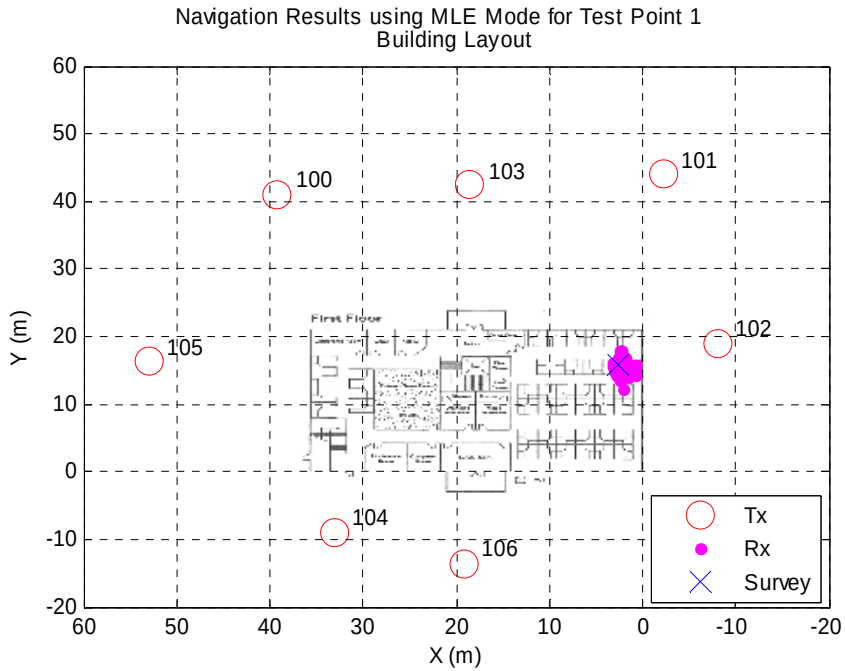
UTC MLE-Aided Filtering Results
Positioning Error

Test Point 1

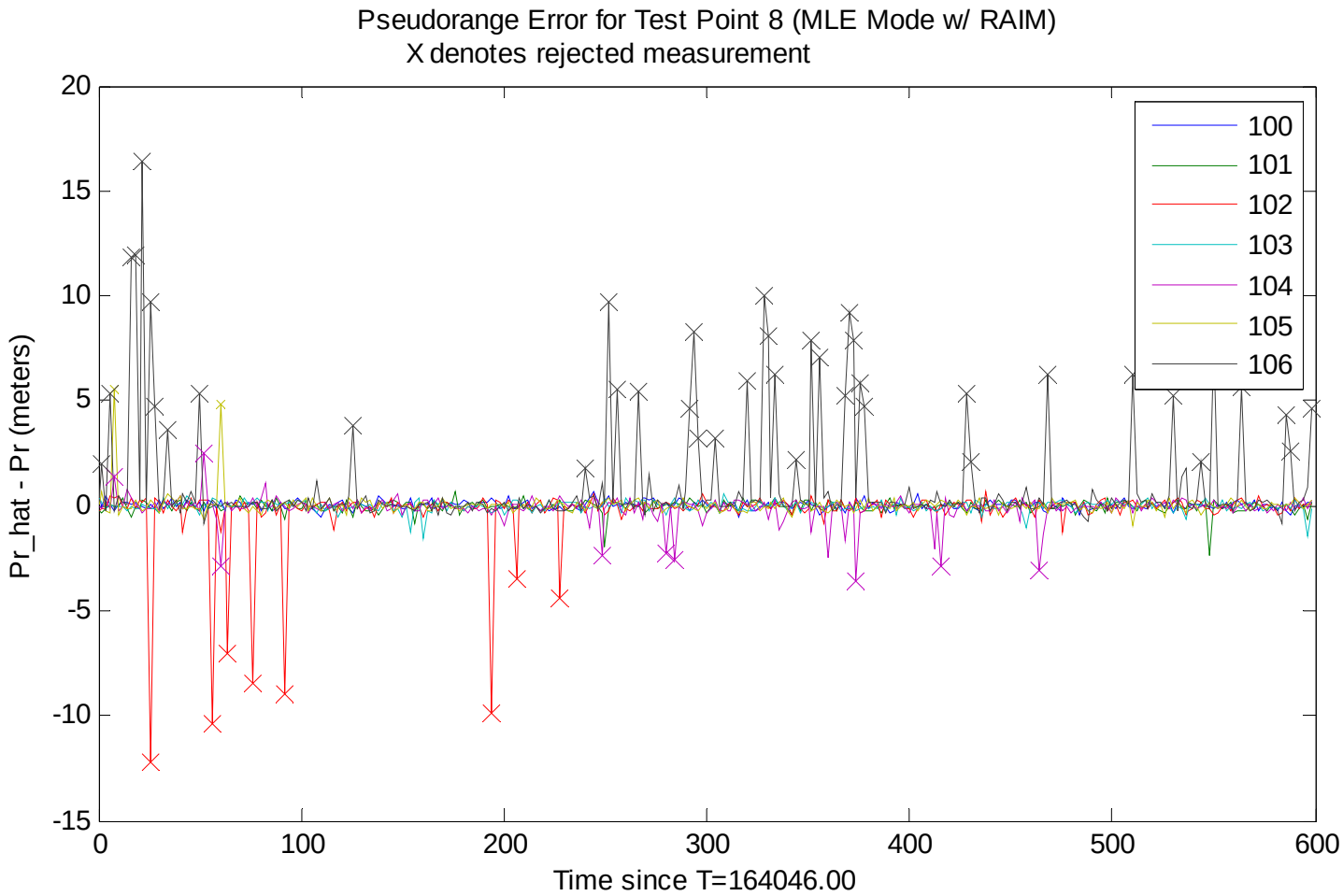
Spline-Based Peak Detection



UTC MLE Peak Detection

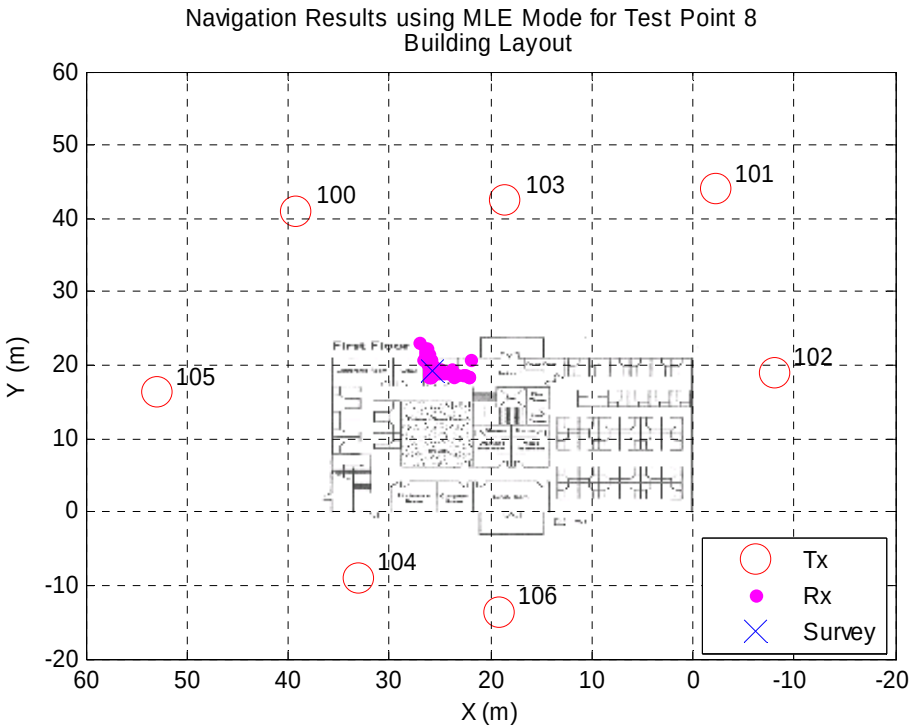


GTI-RAIM Results
Rejected Range Measurements
Test Point 8

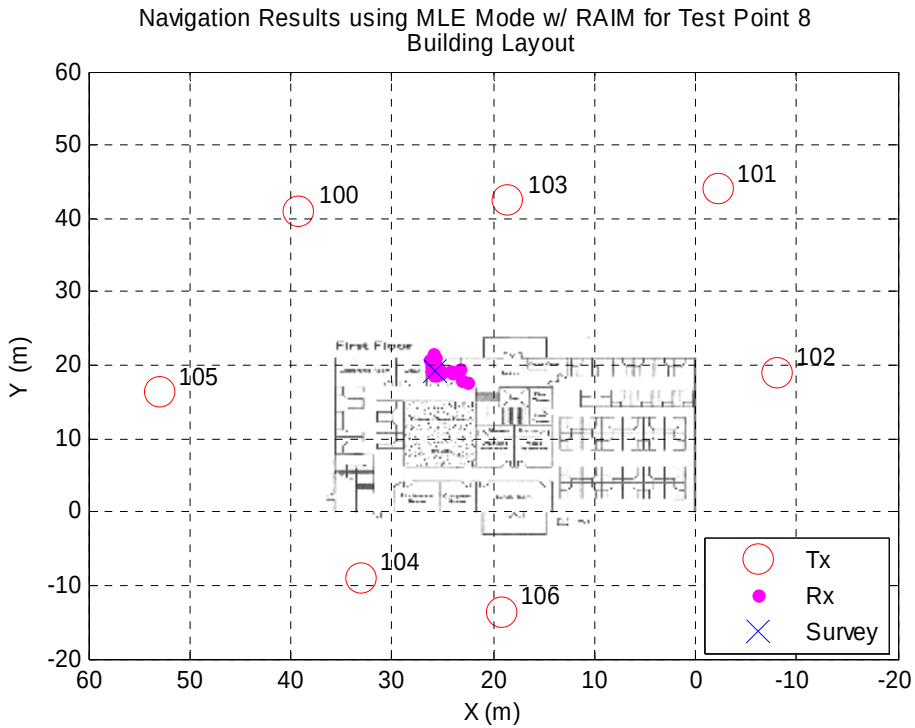


GTI-RAIM Results
Positioning Error
Test Point 8

Without GTI-RAIM



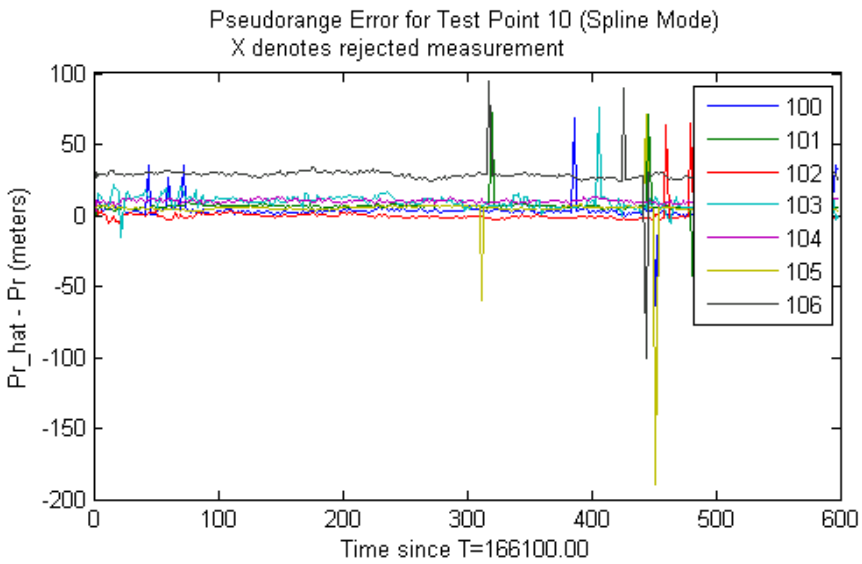
With GTI-RAIM



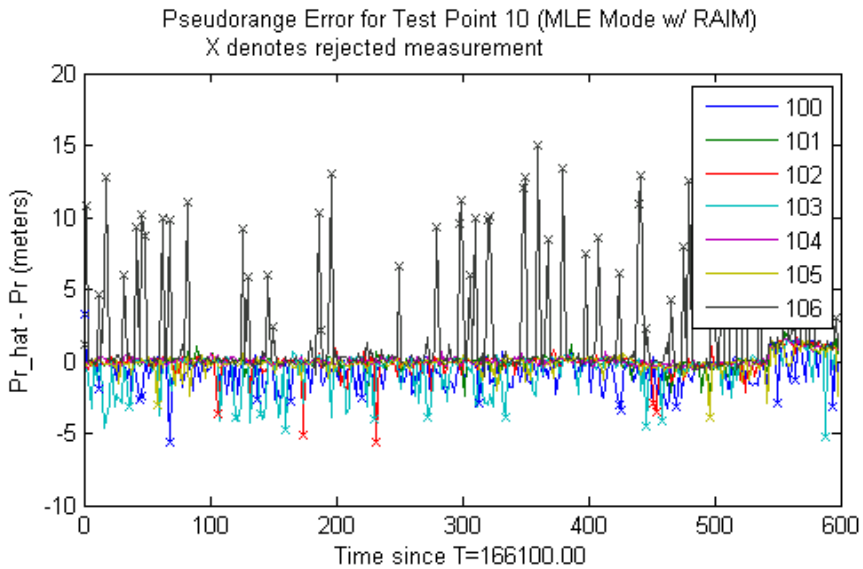
UTC MLE + GTI-RAIM Ranging Error

Test Point 10

Standard Spline without RAIM



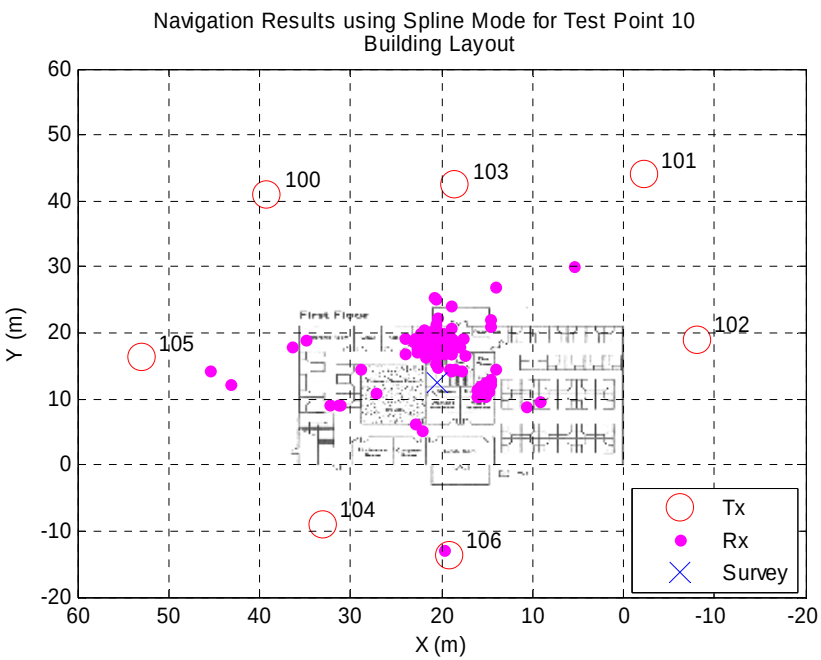
UTC MLE with RAIM



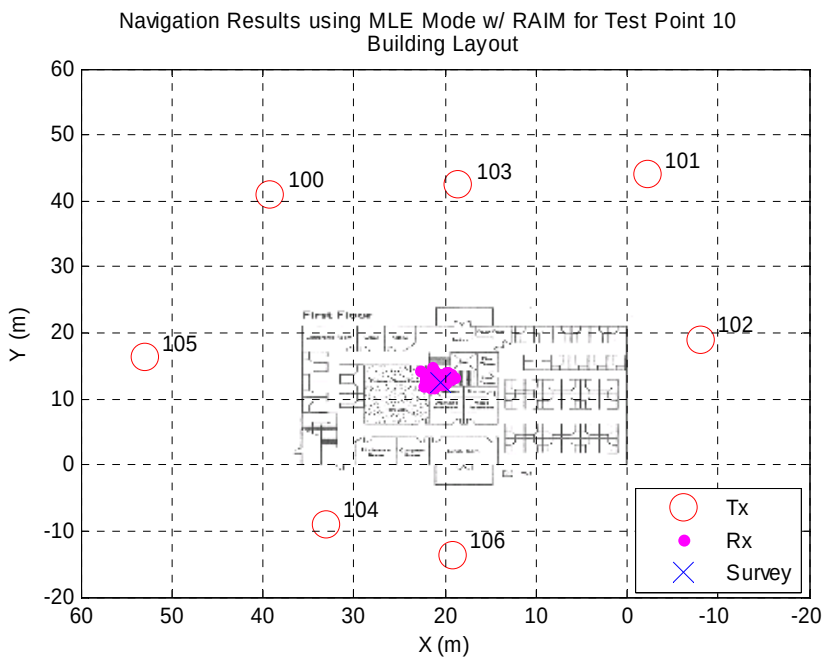
UTC MLE + GTI-RAIM Positioning Error

Test Point 10

Standard Spline without RAIM



UTC MLE with RAIM



Conclusion

- 900 MHz TOA Assistance
  - Can provide augmented navigation to units operating inside buildings and in urban environments
  - Algorithms developed for use on 900 MHz beacons can be easily adapted to handle other signals of opportunity in indoor and urban environments
- UTC-MLE Tracking
  - Enables direct path tracking under very strong fading conditions and in high multipath environments
- GTI-RAIM
  - Redundant measurements allow for FDE algorithms to prevent multipath interference from corrupting the integrated solution
- Potential Applications
  - Military Operations in Urban Terrain
  - First Responder geolocation